

(10) **Patent No.:** US 9,488,731 B2  
(45) **Date of Patent:** \*Nov. 8, 2016

- (56)
- References Cited**

- U.S. PATENT DOCUMENTS

- |              |    |         |                  |
|--------------|----|---------|------------------|
| 5,754,657    | A  | 5/1998  | Schipper et al.  |
| 5,757,916    | A  | 5/1998  | MacDoran et al.  |
| 6,934,631    | B2 | 8/2005  | Dentinger et al. |
| 7,609,201    | B2 | 10/2009 | Masuda           |
| 7,969,354    | B2 | 6/2011  | Levin et al.     |
| 2009/0195354 | A1 | 8/2009  | Levin et al.     |
| 2009/0195443 | A1 | 8/2009  | Levin et al.     |

- (Continued)

- FOREIGN PATENT DOCUMENTS

WO WO2007083270 A1 7/2007

- ## OTHER PUBLICATIONS

- International Search Report and Written Opinion of the International Searching Authority mailed on Feb. 22, 2013 for PCT/US2012/053810 application filed on Sep. 5, 2012, priority date: Sep. 5, 2011.

- (Continued)

*Primary Examiner* — El Hadji Sall

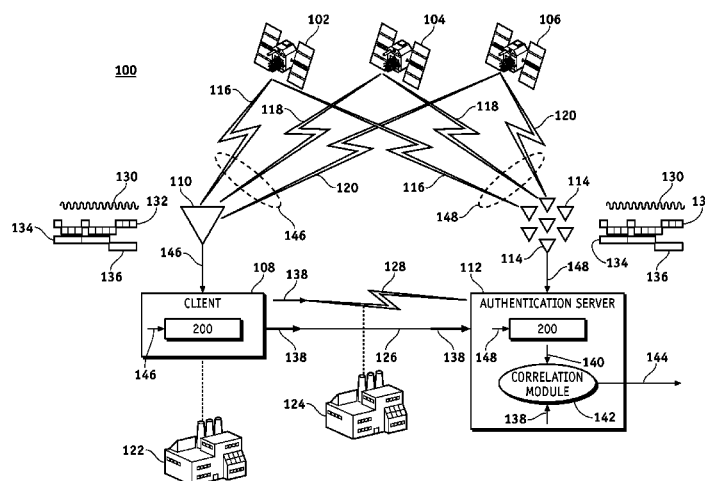
(74) *Attorney, Agent, or Firm* — McDonnell Boehnen  
Hulbert & Berghoff LLP

- (57) **ABSTRACT**

- A system and methods for location authentication are presented. A subset of demodulated server received navigation signals are selected synchronized to client bit frames to provide synchronized server bit frames. A function of the synchronized server bit frames is computed to provide a server signature set. A client signature set and the server signature set are compared to provide a comparison result, and a location of a client device is authenticated based on the comparison result.

- 16 Claims, 12 Drawing Sheets**

- (58) **Field of Classification Search**  
USPC ..... 709/200, 224, 229; 726/3  
See application file for complete search history.



(56)

**References Cited**

U.S. PATENT DOCUMENTS

2010/0134352 A1\* 6/2010 Thomson et al. .... 342/357.09  
2013/0060955 A1\* 3/2013 Enge ..... 709/229

OTHER PUBLICATIONS

Scott Logab, "Anti-Spoofing and Authentication Signal Architectures for Civil Navigation System", Proceeding of ION GPS/GNSS, vol. 2003, Feb. 1, 2003, pp. 1543-1552, XP002436415.

European Search Report Issued in European Patent Application No. 12772568.7 dated Apr. 29, 2015.

Office Action issued in Canadian Patent Application No. 2,847,948 dated Jun. 4, 2015.

English Translation of First Office Action issued in Japanese Patent Application No. 201280043109.2 dated Jul. 27, 2015.

N. Odeh, "Patent Examination Report No. 1" for Australian Pat. App. No. 2012304672, issued Feb. 18, 2016.

\* cited by examiner

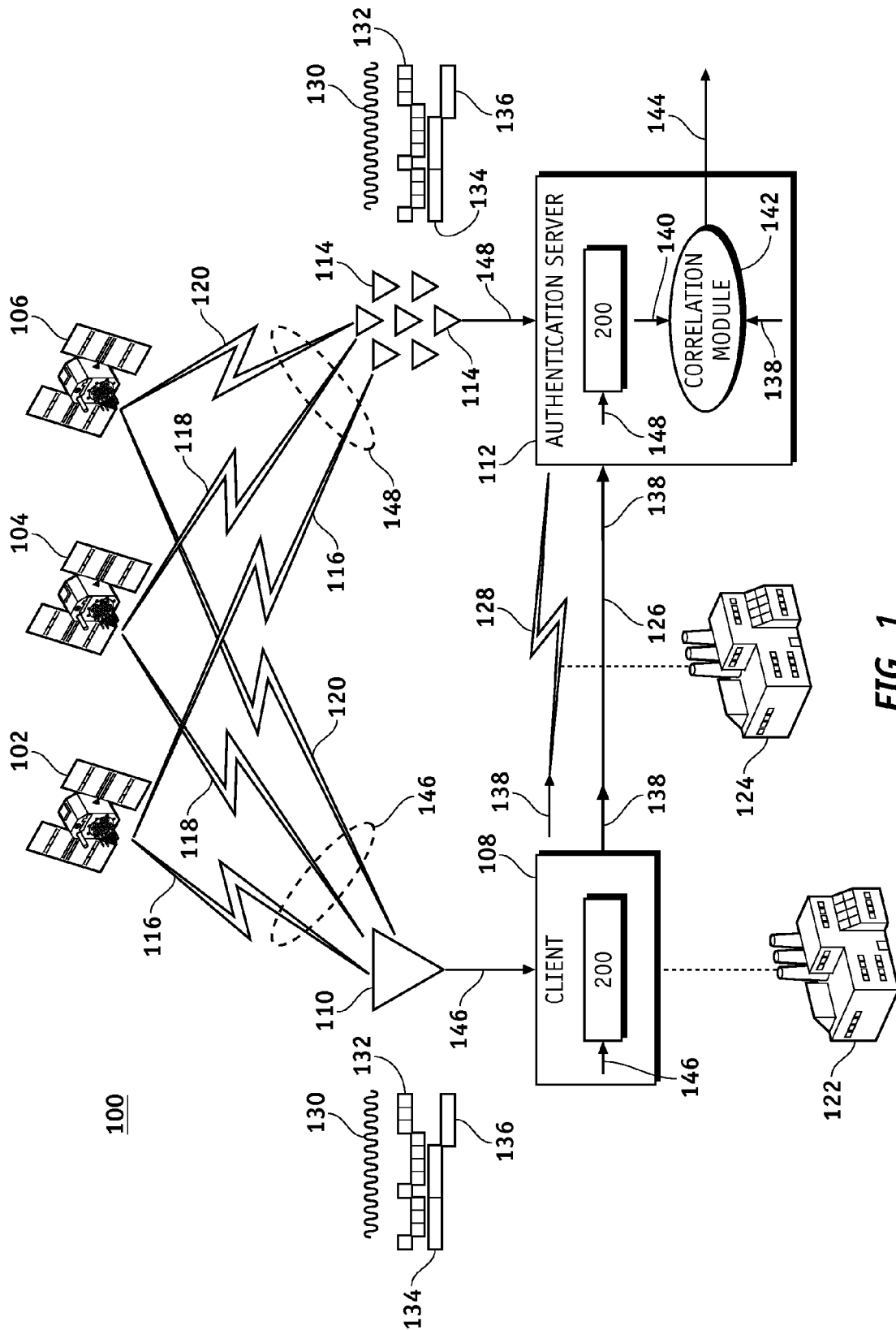


FIG. 1

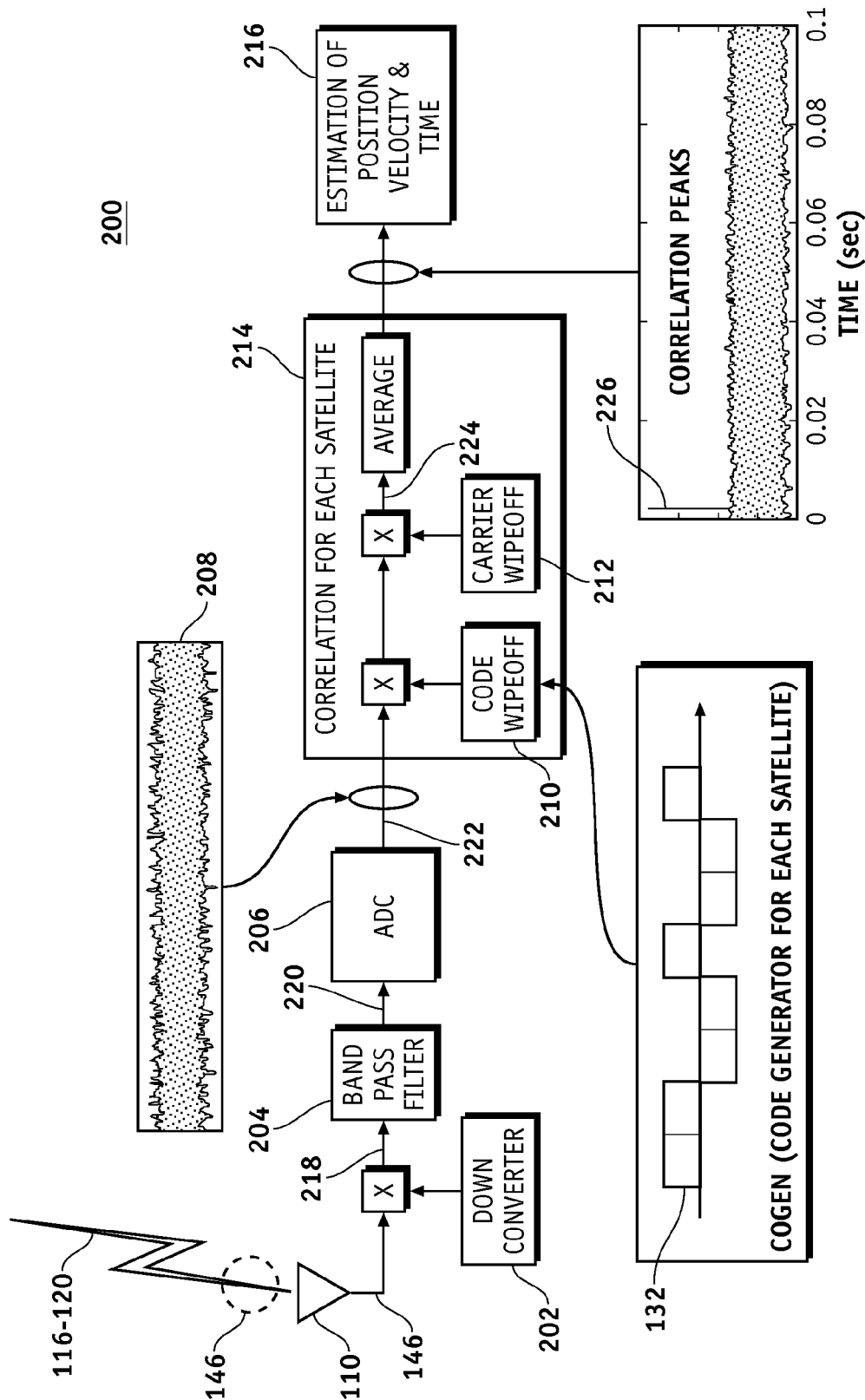
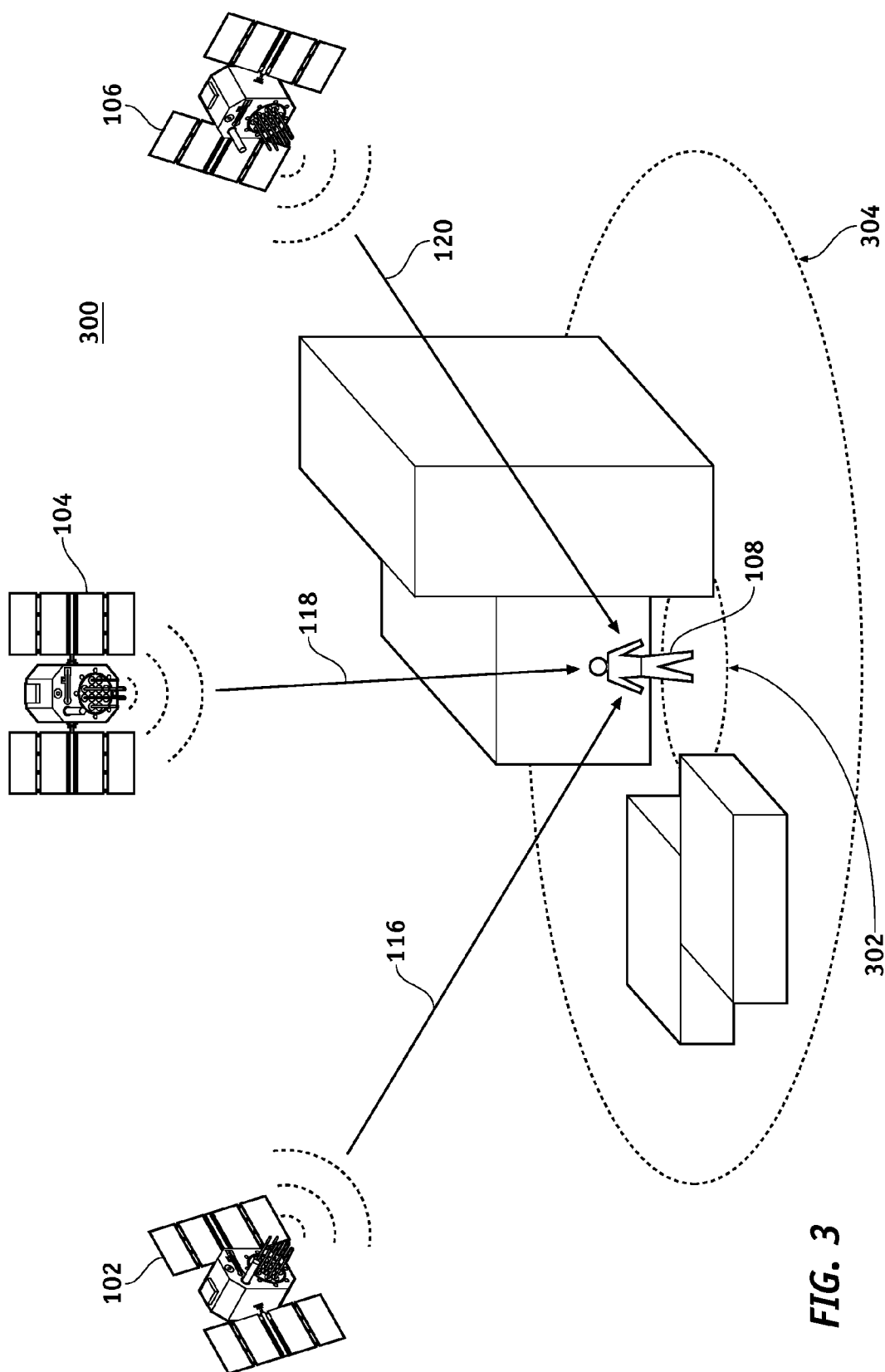
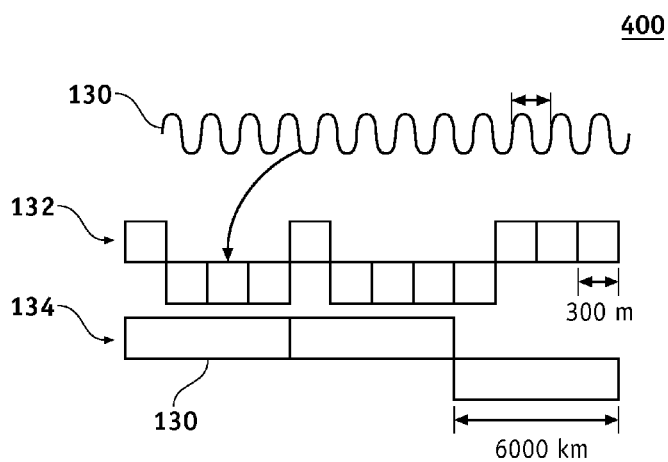
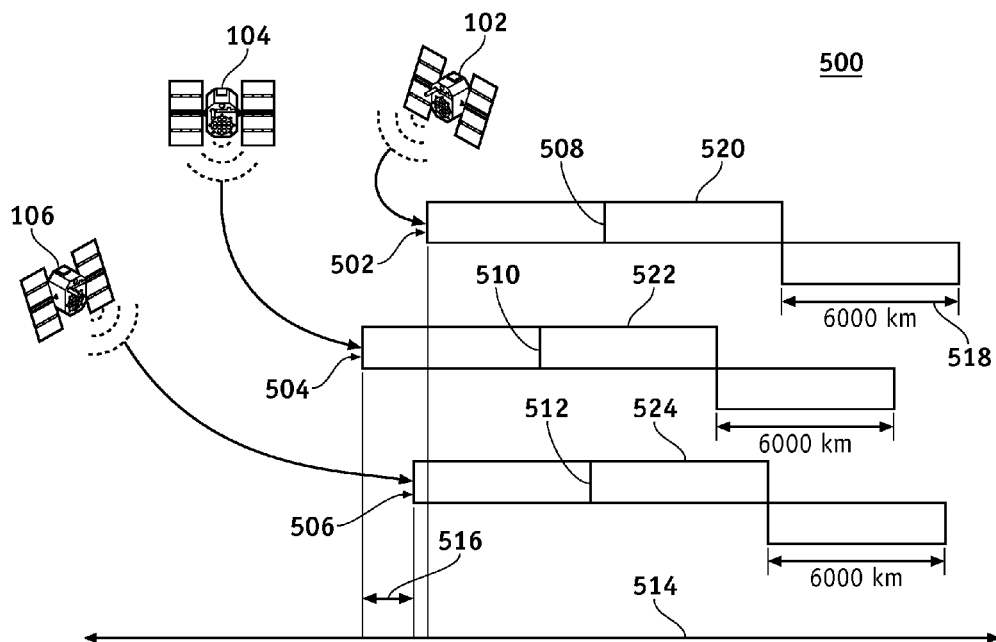


FIG. 2





**FIG. 4**



**FIG. 5**

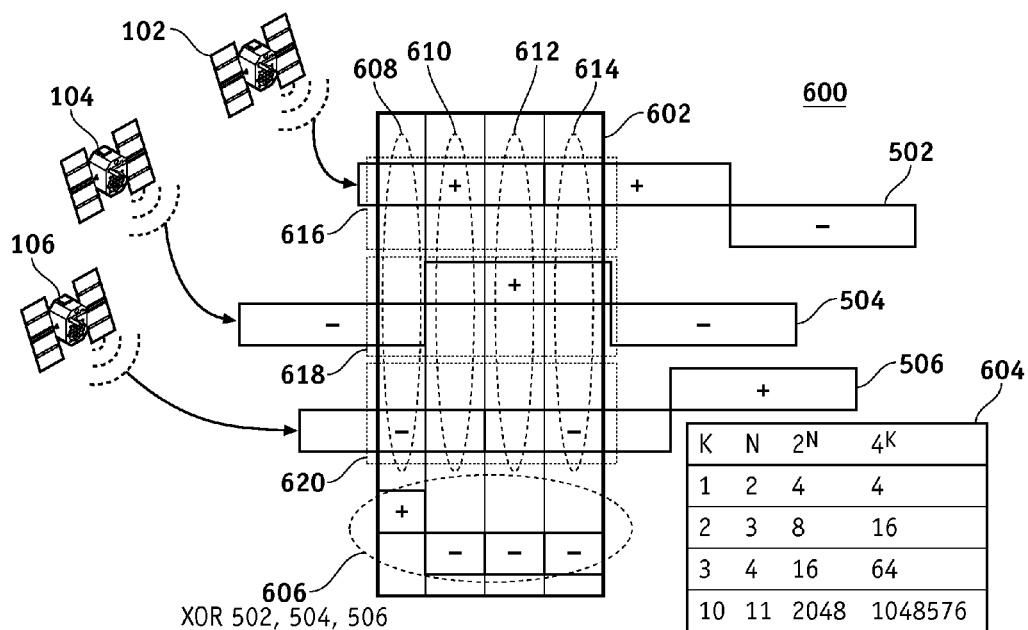


FIG. 6

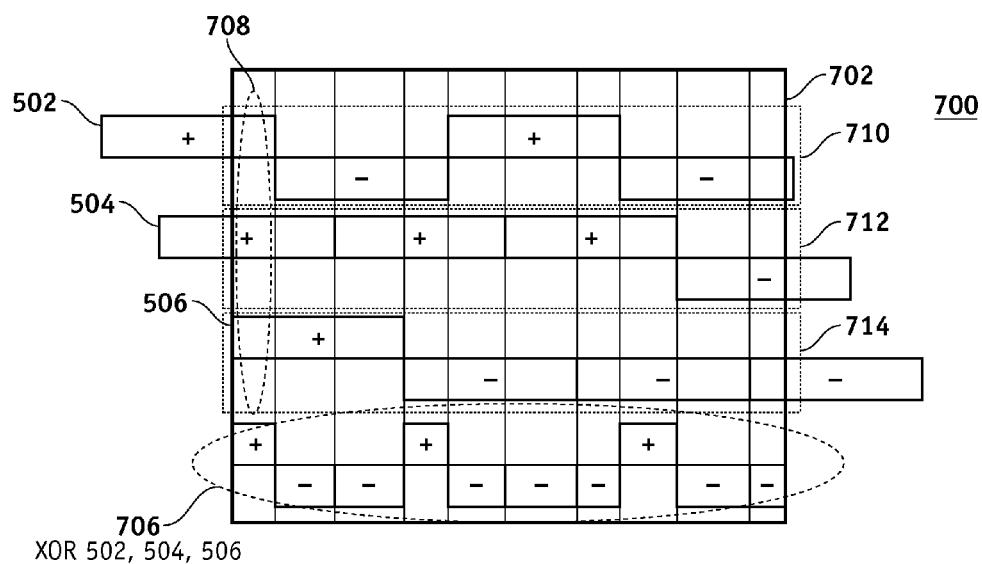
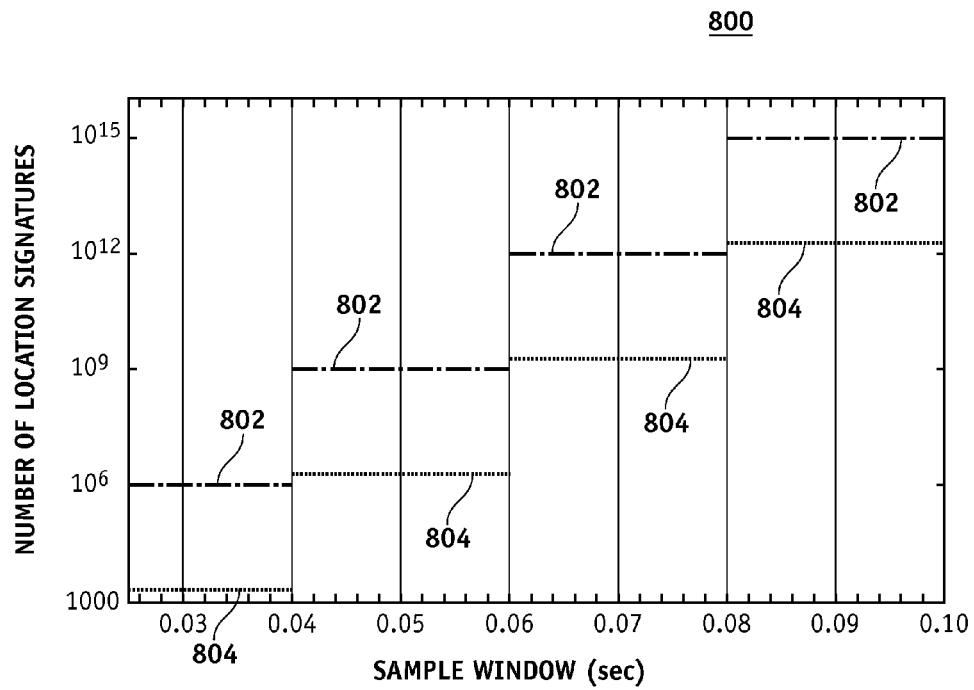
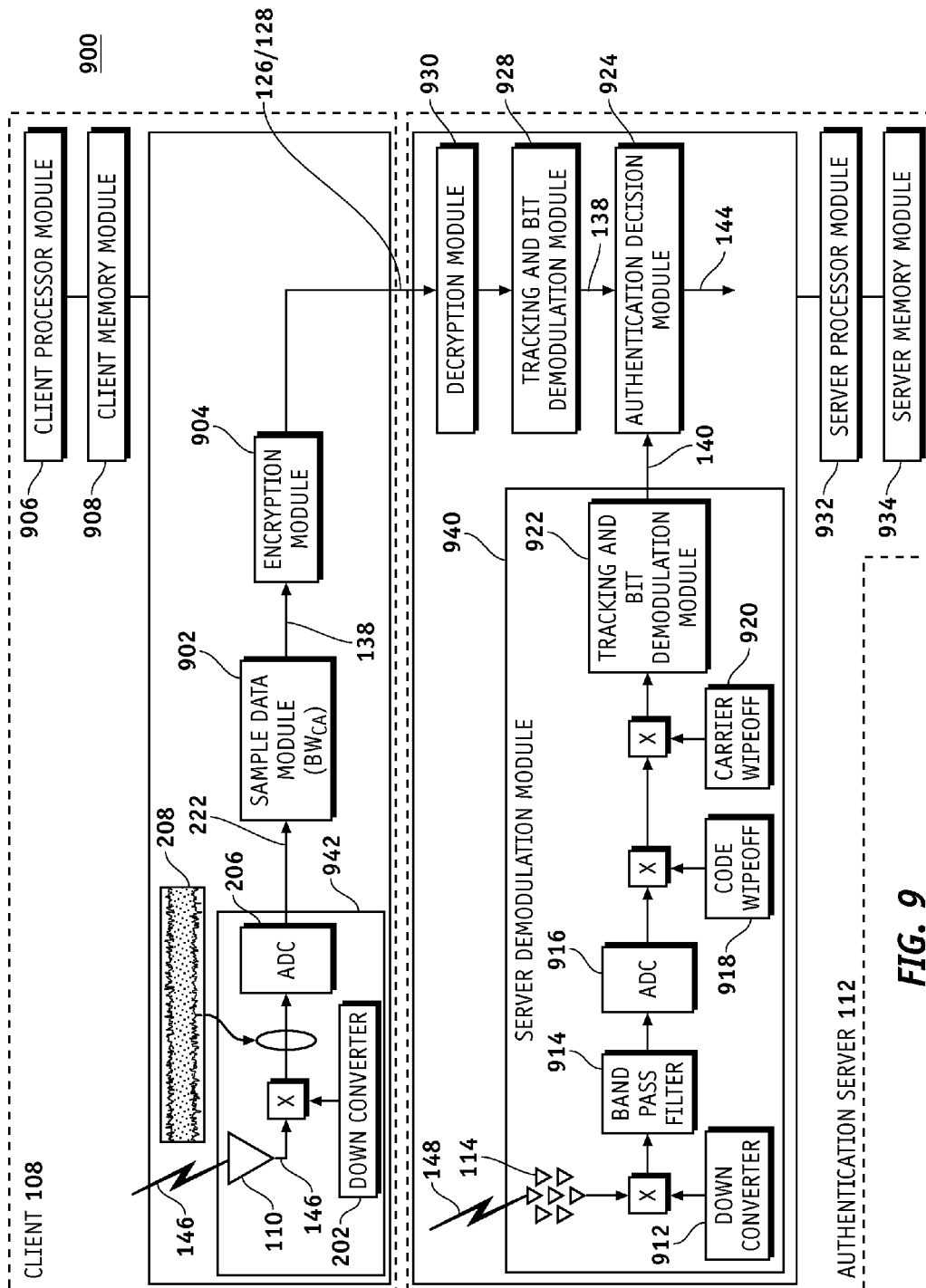


FIG. 7

**FIG. 8**





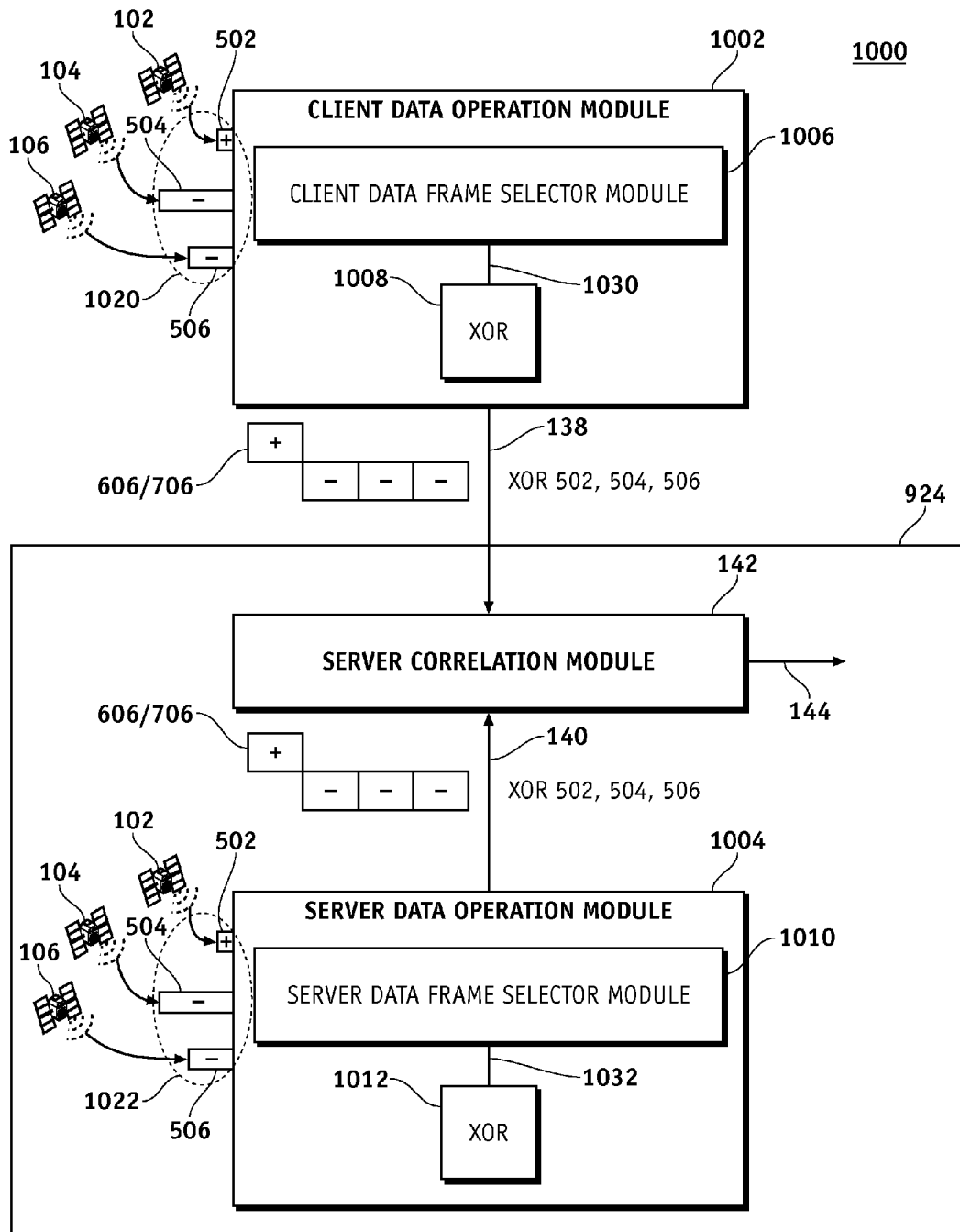


FIG. 10

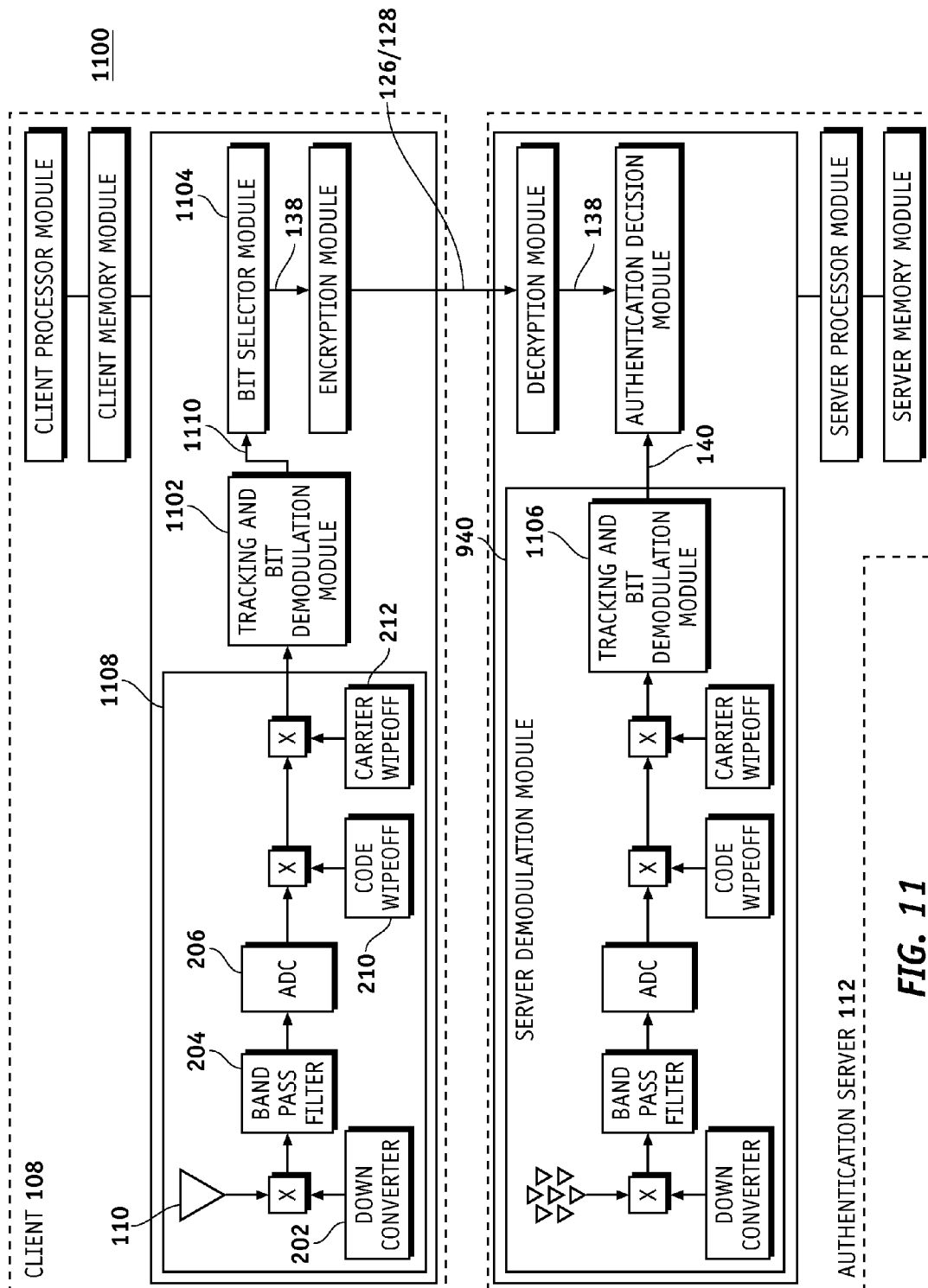
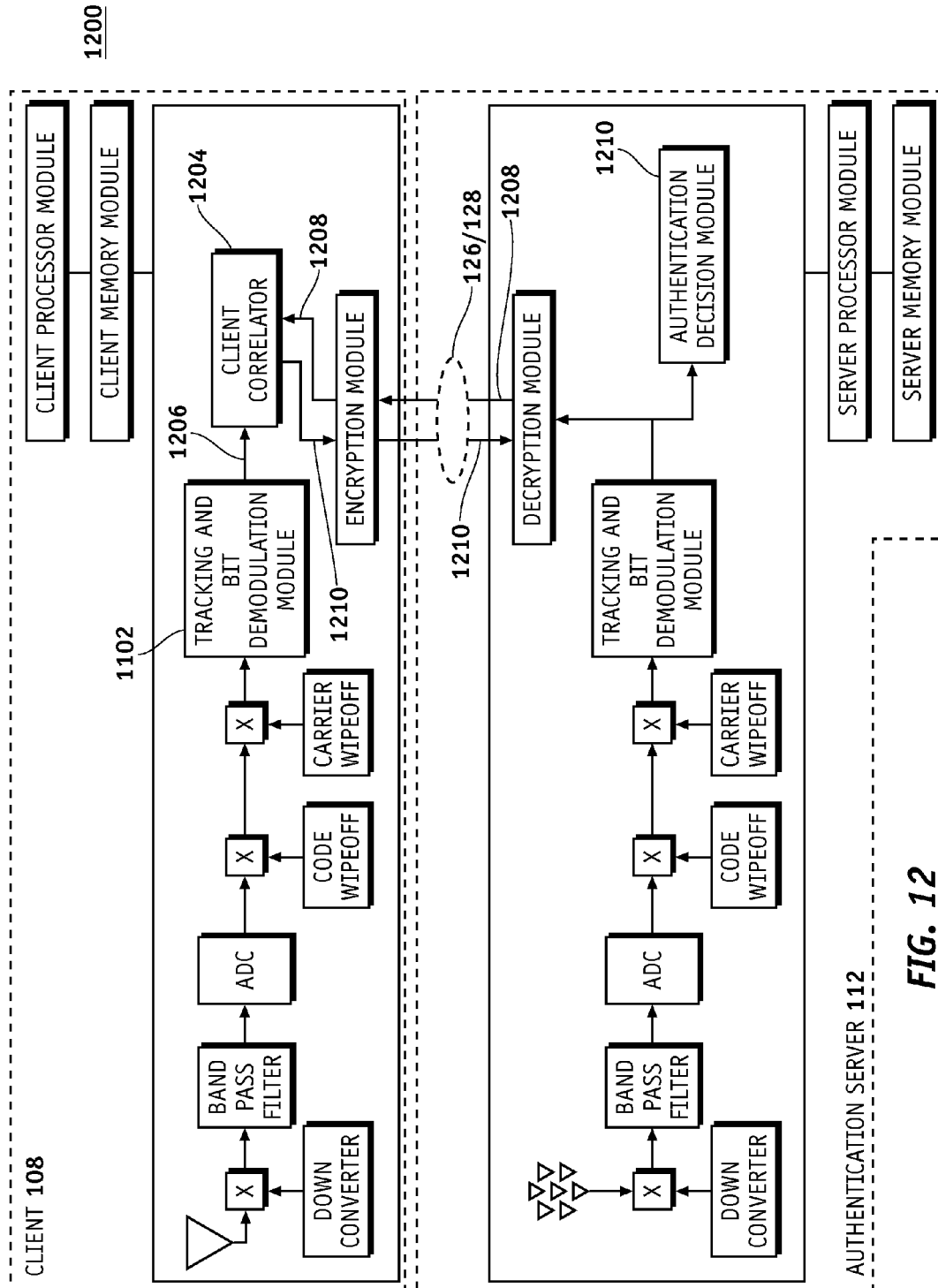
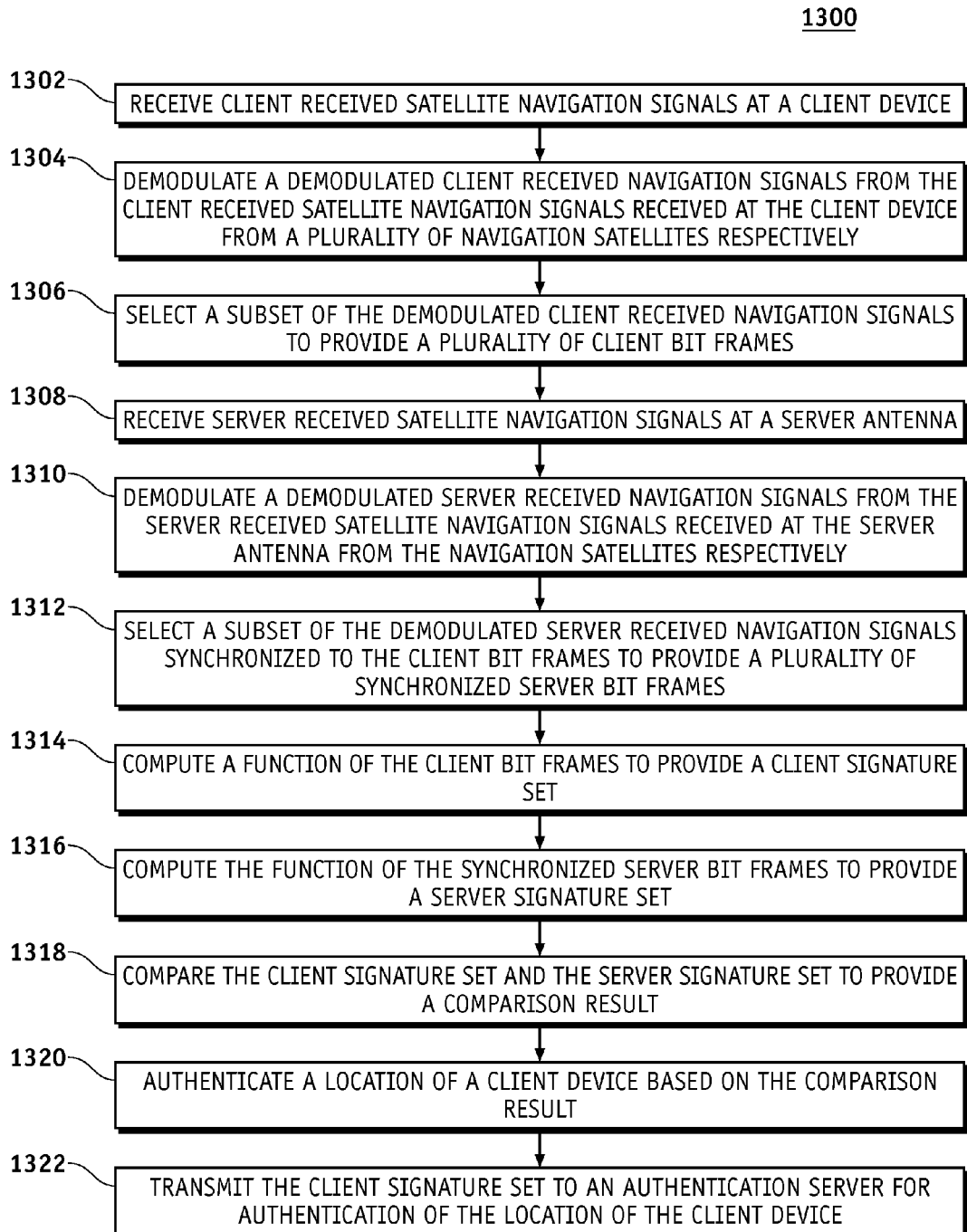
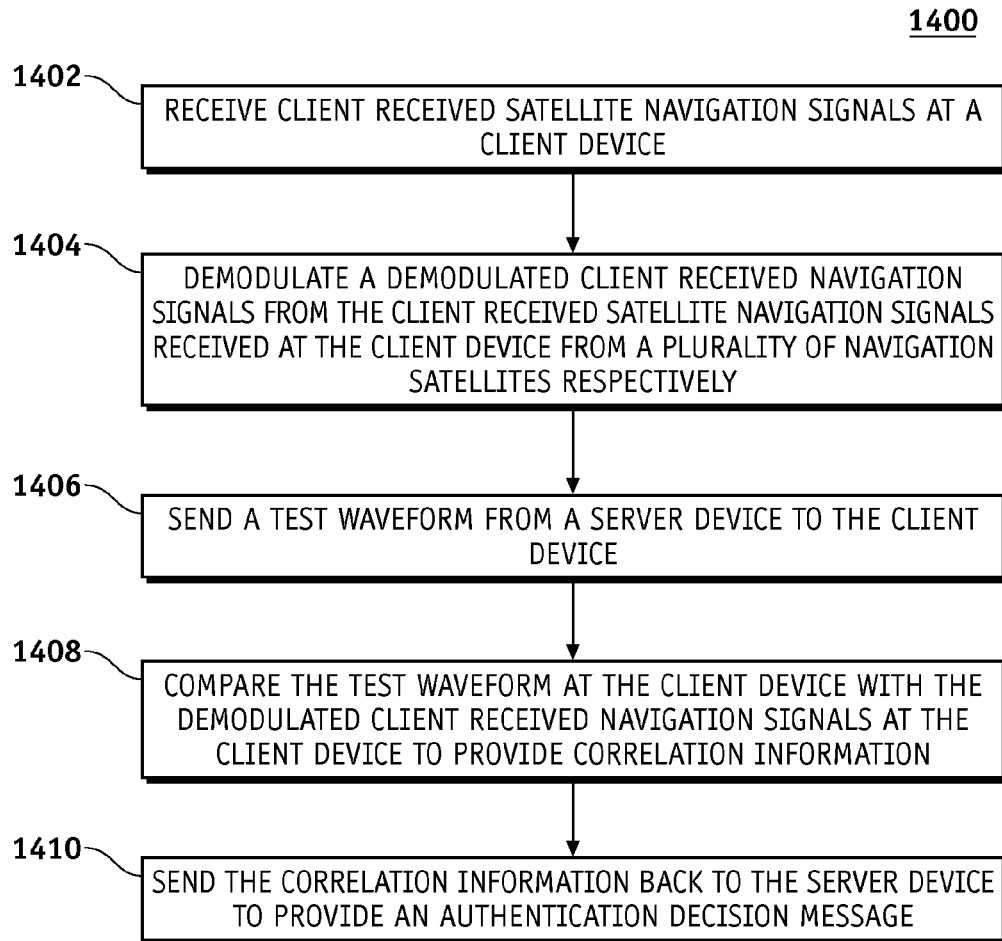


FIG. 11



**FIG. 13**

**FIG. 14**

1

# AUTHENTICATION BASED ON RANDOM BITS IN SATELLITE NAVIGATION MESSAGES

## CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. patent application Ser. No. 13/603,316 filed on Sep. 4, 2012, the content of which is incorporated by reference herein in its entirety.

## FIELD

Embodiments of the present disclosure relate generally to radio communication and navigation systems. More particularly, embodiments of the present disclosure relate to satellite systems for location validation.

## BACKGROUND

A significant fraction of power in a secret signal component of a navigation satellite signal such as a Global Navigation Satellite System (GNSS) signal may be lost when the GNSS signal passes through band pass filters used by a GNSS client device (receiver). The loss of power degrades performance in low signal-to-noise-ratio (SNR) environments. Degraded performance in low SNR environments may prevent or minimize an ability of an authentication system to validate that a global position computation or an assertion based on a global position is bona fide.

## SUMMARY

A system and methods for location authentication are presented. A subset of demodulated server received navigation signals are synchronized to client bit frames to provide synchronized server bit frames. A function of the client bit frames is computed to provide a client signature set. A function of the synchronized server bit frames is computed to provide a server signature set. The client signature set and the server signature set are compared to provide a comparison result, and a location of a client device is authenticated based on the comparison result.

In this manner, embodiments of the disclosure provide an authentication system that enables location authentication for client devices located in low signal-to-noise-ratio (SNR) environments such as indoors and downtown.

In an embodiment, a method for location authentication selects a subset of demodulated server received navigation signals synchronized to client bit frames to provide synchronized server bit frames. The method further computes a function of the synchronized server bit frames to provide a server signature set. The method further compares a client signature set and the server signature set to provide a comparison result, and authenticates a location of a client device based on the comparison result.

In another embodiment, a location authentication system comprises a server data frame selector module, a server data operation module, a server correlation module, and an authenticate module. The server data frame selector module selects a subset of demodulated server received navigation signals synchronized to client bit frames to provide server bit frames. The server data operation module computes a function of the synchronized server bit frames to provide a server signature set. The server correlation module compares a client signature set and the server signature set to

2

provide a comparison result. The authenticate module authenticates a location of a client device based on the comparison result.

In a further embodiment, a non-transitory computer readable storage medium comprises computer-executable instructions for location authentication. The computer-executable instructions select a subset of demodulated client received navigation signals to provide client bit frames. The computer-executable instructions further compute a function of the client bit frames to provide a client signature set. The computer-executable instructions further transmit the client signature set to an authentication server for authentication of a location of a client device.

This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the detailed description. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

## BRIEF DESCRIPTION OF DRAWINGS

A more complete understanding of embodiments of the present disclosure may be derived by referring to the detailed description and claims when considered in conjunction with the following figures, wherein like reference numbers refer to similar elements throughout the figures. The figures are provided to facilitate understanding of the disclosure without limiting the breadth, scope, scale, or applicability of the disclosure. The drawings are not necessarily made to scale.

FIG. 1 is an illustration of an exemplary wireless communication environment for authenticating an asserted location based on navigation satellite signals according to an embodiment of the disclosure.

FIG. 2 is an illustration of an exemplary simplified functional block diagram of a navigation satellite receiver.

FIG. 3 is an illustration of an exemplary wireless communication environment showing ways in which indoor and downtown environments can attenuate navigation satellite signals.

FIG. 4 is an illustration of an exemplary diagram showing a navigation message of a navigation satellite.

FIG. 5 is an illustration of an exemplary diagram showing overlap of navigation messages from three navigation satellites.

FIG. 6 is an illustration of an exemplary diagram showing the navigation messages from the three navigation satellites shown in FIG. 5 are sampled over slightly greater than one bit duration according to an embodiment of the disclosure.

FIG. 7 is an illustration of an exemplary diagram showing the navigation messages from the three satellites shown in FIG. 5 are sampled over several bit durations according to an embodiment of the disclosure.

FIG. 8 is an illustration of an exemplary diagram showing a number of location signatures that can be provided according to two embodiments of the disclosure.

FIG. 9 is an illustration of an exemplary functional block diagram of an authentication system according to an embodiment of the disclosure.

FIG. 10 is an illustration of an exemplary functional block diagram of an authentication system according to an embodiment of the disclosure.

FIG. 11 is an illustration of an exemplary functional block diagram of an authentication system according to an embodiment of the disclosure.

3

FIG. 12 is an illustration of an exemplary functional block diagram of an authentication system according to an embodiment of the disclosure.

FIG. 13 is an illustration of an exemplary flowchart showing an authentication process according to an embodiment of the disclosure.

FIG. 14 is an illustration of an exemplary flowchart showing an authentication process according to an embodiment of the disclosure.

#### DETAILED DESCRIPTION

The following detailed description is exemplary in nature and is not intended to limit the disclosure or the application and uses of the embodiments of the disclosure. Descriptions of specific devices, techniques, and applications are provided only as examples. Modifications to the examples described herein will be readily apparent to those of ordinary skill in the art, and the general principles defined herein may be applied to other examples and applications without departing from the spirit and scope of the disclosure. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding field, background, summary or the following detailed description. The present disclosure should be accorded scope consistent with the claims, and not limited to the examples described and shown herein.

Embodiments of the disclosure may be described herein in terms of functional and/or logical block components and various processing steps. It should be appreciated that such block components may be realized by any number of hardware, software, and/or firmware components configured to perform the specified functions. For the sake of brevity, conventional techniques and components related to communication systems, network protocols, global positioning systems, and other functional aspects of the systems (and the individual operating components of the systems) may not be described in detail herein.

Embodiments of the disclosure are described herein in the context of a non-limiting application, namely, an authentication system for a mobile phone application. Embodiments of the disclosure, however, are not limited to such mobile phone applications, and the techniques described herein may also be utilized in other applications. For example, embodiments may be applicable to a desktop computer, a laptop or notebook computer, an iPod™, an iPod™, a mainframe, a server, a client, or any other type of special or general purpose computing device as may be desirable or appropriate for a given application or environment.

As would be apparent to one of ordinary skill in the art after reading this description, the following are examples and embodiments of the disclosure and are not limited to operating in accordance with these examples. Other embodiments may be utilized and changes may be made without departing from the scope of the exemplary embodiments of the present disclosure.

Embodiments of the disclosure provide an authentication system that provides adequate received signal strength for a navigation satellite signal to be received at a client device (client) located in a low signal-to-noise-ratio (SNR) environment such as indoors in a city building.

FIG. 1 is an illustration of an exemplary wireless communication environment 100 (environment 100) for authenticating an asserted location based on navigation satellite signals according to an embodiment of the disclosure. The environment 100 may comprise navigation satellites 102, 104 and 106, a client 108 comprising a satellite receiver 200

4

(navigation satellite receiver 200), and an authentication server 112 comprising a satellite receiver 200 (navigation satellite receiver 200).

Each of the navigation satellites 102-106 may comprise a Global Navigation Satellite System (GNSS) satellite, a Global Positioning System (GPS™) satellite, a Globalnaya Navigatsionnaya Sputnikovaya Sistema (GLONASS™) satellite, a BeiDou Navigation System (COMPASS™) satellite, a Galileo™ satellite, or other navigation satellite.

Navigation satellite signals 116, 118 and 120 transmitted from the navigation satellites 102, 104 and 106 respectively can be processed at the client 108 to determine a velocity, a time and a location 122 of the client 108. However, navigation satellite signals may be spoofed in existing systems such that an existing client senses and/or reports a false position 124. Spoofing is becoming of general concern because navigation satellites are increasingly being used to support location transactions that have financial value or safety-of-life implications.

Each of the navigation satellite signals 116-120 comprises a signal 130 at a frequency (carrier frequency) such as a GPS L1 frequency, which is used as a carrier (in-phase carrier 130) to modulate a data signal that is modulated with a spreading code such as a Code Division Multiple Access (CDMA) code, commonly referred to as a “Coarse/Acquisition” (C/A) code (spectrum-spreading code 132). For a GPS system, the C/A code may be variously known as “Coarse/Acquisition”, “Clear/Access”, and “Civil/Access”. Each of the navigation satellites 102-106 transmits at least one other signal employing the carrier frequency that is shifted 90 degrees (Quadrature signal, not shown). The at least one other signal (second signal) is modulated by another code, known as an encrypted “P(Y)” code (not shown). The P(Y) code is either a “precision” (P) code, which is publicly known, or an encrypted “Y” code. Many GNSS satellites use the Y code and, consequently, a resulting transmitted signal that is encoded with the Y code cannot be used by other than those having a decryption algorithm and a key for the Y code.

In addition, a navigation message 134 modulates both the (known) P and the (unknown) Y code broadcast by the navigation satellites 102, 104, 106.

For example, in commercial applications, the C/A code is publicly known and, consequently, an existing navigation satellite receiver can be vulnerable to spoofing. In existing systems, a hostile party can generate a facsimile of one or more satellite signals that carry incorrect information. An existing navigation satellite receiver at a client device that accepts the bogus signals may be spoofed to compute an incorrect position, and may be spoofed to compute a position that the hostile party wishes to have the existing navigation satellite receiver compute. Spoofing may be ineffective on those able to use the Y code because this code is not publicly known, so a hostile party should not be able to create a signal that appears bona fide.

However, a significant fraction of signal power in the (secret) Y code signal component may be lost when each of the navigation satellite signals 116-120 pass through a band pass filter used by the navigation satellite receiver 200 at the client 108. Loss of signal power may degrade performance of the client 108 in low signal-to-noise-ratio (SNR) environments. Degrading performance may reduce an ability of the authentication server 112 to provide confidence that a global position computation, or an assertion based on a global position, is bona fide.

Embodiments of the disclosure provide a means for authenticating the location 122 based on random or pseudo-



5

random information contained in the navigation message **134** broadcast by the navigation satellites **102**, **104**, **106** or other navigation transmitters. Thereby, an improved coverage is provided where the navigation satellite signals **116-120** can be obstructed as compared to existing methods.

The client **108** comprises the navigation satellite receiver **200** and is configured to track and locate the client **108** based on receiving the navigation message **134** of each of the navigation satellite signals **116-120** through client received satellite navigation signals **146** (client received navigation signals **146**) via a client antenna **110**. The client **108** is configured to estimate navigation data bits **136** contained in the navigation message **134** of a multiplicity of the client received navigation signals **146** to provide client bit frames **1030** (comprising navigation messages **502/504/506** demodulated from the client received navigation signals **146**, FIG. **10**). In one embodiment, the client **108** computes a function such as an exclusive OR (XOR) **1008** (FIG. **10**) across the client bit frames **1030** (i.e., from the navigation satellites **102**, **104**, **106**) to provide a client signature set **138** of a client asserted location for the location **122** as explained in more detail below.

The client **108** may support many consumer applications. For example, many financial transactions utilize cell phones as the client **108** indoors in a city building. The client **108** may comprise, wired or wireless communication devices such as, but without limitation, a desktop computer, a laptop or notebook computer, an iPod™, an iPod™, a mainframe, a server, or other type of special or general purpose computing device that comprises a receiver such as the navigation satellite receiver **200** capable of receiving the client received navigation signals **146**, and as may be desirable or appropriate for a given application or environment.

The authentication server **112** is configured to receive or estimate (calculate) the client signature set **138** for the location **122**. The authentication server **112** may receive the client signature set **138** via a wired communication link **126**, a wireless communication channel **128**, a combination thereof, or estimate (calculate) the client signature set **138** locally at the authentication server **112**. The authentication server **112** comprises the navigation satellite receiver **200** and is also configured to receive the navigation message **134** (navigation messages) of the navigation satellite signals **116-120** through server received navigation signals **148** via a server antenna **114**.

The authentication server **112** also estimates navigation data bits **136** contained in the navigation message **134** of the server received navigation signals **148** synchronized to the client bit frames **1030** to provide synchronized server bit frames **1032** (FIG. **10**). The authentication server **112** computes a function of the synchronized server bit frames **1032** to provide a server signature set **140** as explained in more detail below. In one embodiment, the client signature set **138** and the server signature set **140** are compared by a server correlation module **142** to generate an authentication decision message **144**. The authentication server **112** determines a validity of an asserted location of the location **122** of the client **108** based on the navigation message **134**, and generates the authentication decision message **144** indicating validity or invalidity of the asserted location. Validity indicates there is acceptable accuracy and/or certainty that the client **108** is located at the asserted location, and invalidity indicates there is not acceptable accuracy and/or certainty that the client **108** is located at the asserted location.

Many financial transactions utilize cell phones as the client **108** in an “indoors” or “downtown” environment, where they occur on platforms that are low cost and oper-

6

ating in obstructed signal environments. Two criteria may be important to a design of such a cost-effective navigation satellite-based authentication system. First, data should be available from the navigation satellite receiver **200** included in the cell phone. Second, the navigation satellite-based authentication system should compensate for the client received navigation signals **146** that are expected where cell phone users congregate e.g., “indoors” and “downtown”. The first criterion is reflected in FIG. **2** that shows basic signal processing steps in the navigation satellite receiver **200**. The second criterion for a navigation satellite-based authentication system is depicted in FIG. **3**.

FIG. **2** is an illustration of an exemplary simplified functional block diagram of the navigation satellite receiver **200** shown in FIG. **1**. The navigation satellite receiver **200** may comprise, for example but without limitation, a GPS receiver, or other satellite receiver. As shown in FIG. **2**, the navigation satellite receiver **200** receives radio frequency signals such as the client received satellite navigation signals **146** at the client antenna **110**. The navigation satellite receiver **200** then demodulates the client received navigation signals **146** from the navigation satellite signals **116-120** received at the client **108** from the navigation satellites **102-108** respectively. The navigation satellite receiver **200** demodulates the client received navigation signals **146** from the navigation satellite signals **116-120** received at the client **108** by down converting the client received navigation signals **146** from Radio Frequency (RF) to baseband by the down convertor **202** and band pass filtering the down converted client received navigation signals **218** by the band pass filter **204**.

As mentioned above, a significant fraction of a power in the secret Y code signal component of the navigation satellite signals **116-120** or the client received navigation signals **146** may be lost when the client received navigation signals **146** pass through the band pass filter **204**. For GPS, signals modulated by the secret Y code signals have a noise equivalent bandwidth of 10 MHz, whereas the noise equivalent bandwidth of civil C/A code signals (C/A code) is about 1 MHz. The civil C/A code signals are utilized by the navigation satellite receiver **200** in the client **108** such as cell phones, not the secret Y code signals. Hence, the band pass filter **204** in cell phones generally has a bandwidth of only a few MHz, and so an appreciable fraction of signal power of signals comprising the secret Y codes is lost. Loss of signal power degrades performance in low signal-to-noise-ratio (SNR) environments. Degraded performance may prevent or minimize an ability of the authentication server **112** to validate that a global position computation, or an assertion based on a global position, is bona fide.

The navigation satellite receiver **200** then converts band pass filtered client received navigation signals **220** from analog signals to digital signals by an analog to digital converter (ADC) **206** to provide digital client received navigation signals **222**. The navigation satellite receiver **200** then removes the spectrum-spreading code **132** (C/A code) from the digital client received navigation signals **222** by a code wipe-off **210**. The navigation satellite receiver **200** then removes the in-phase carrier **130** from the digital client received navigation signals **222** by a carrier wipe-off **212** to provide clean digital client received navigation signals **224**.

The navigation satellite receiver **200** then correlates the clean digital client received navigation signals **224** with a replica of the clean digital client received navigation signals **224** at the client **108** using a correlation module **214** to estimate the location **122**, a velocity and a time offset of the client **108** at an output **216** based on a correlation peak **226**.

The location **122** can be computed using more than a minimum number of satellites (4 satellites to compute latitude, longitude, elevation, and navigation satellite/GPS time).

FIG. 3 is an illustration of an exemplary wireless communication environment (environment **300**) showing indoor and downtown environments can attenuate the navigation satellite signals **116-120**. A nominal received signal strength **304** of the received GPS signal is approximately  $-130$  dBm (or  $10\text{E}-16$  Watts). The navigation satellite receiver **200** in the client **108** under open sky can expect the nominal received signal strength **304**. However, the client **108** such as a cell phone may operate indoors in a city building where an attenuated received signal strength **302** drops to  $-140$  dBm or  $-160$  dBm or even weaker. Thus, the authentication server **112** should operate at these lower levels of the attenuated received signal strength **302**.

FIG. 4 is an illustration of an exemplary diagram **400** showing a signal structure of the navigation messages **134** of the navigation satellite **102**. The navigation messages **134** modulates both the known (P) code and the unknown (Y) code (not shown) broadcast by for example the navigation satellite **102**, via the navigation satellite signal **116**. Embodiments of the disclosure are based on random (pseudo-random) information contained in the navigation messages **134** broadcast by the navigation satellite **102** or other navigation transmitters. For GNSS, the navigation message(s) **134** are broadcast at 50 to 1000 bit per second (bps), and are thus distinct from spectrum-spreading codes such as the unknown (Y) code (not shown) and the C/A code (spectrum-spreading code **132**) that also modulate the navigation satellite signals **116** from the navigation satellite **102**. The navigation messages **134** vary slowly at 50-1000 bit per second compared to the (underlying) spectrum-spreading code **132** at 1.023 Mcps (C/A code) or spectrum-spreading code at 10.23 Mcps (Y code, not shown).

The navigation message(s) **134** for the navigation satellite **102** comprise information such as location and time of the navigation satellite **102**, a coarse location of the navigation satellites **104**, **106** other than the navigation satellite **102**, and other information. Unlike the unknown or secret code (Y), the navigation messages **134** are not attenuated by the band pass filter **204** (FIG. 2), and pass through the band pass filter **204** when the navigation satellite signal **116** passes through the band pass filter **204**. Thereby, using the navigation messages **134** in low signal-to-noise-ratio (SNR) environments provide confidence for a satellite-based authentication system to validate that a global position computation, or an assertion based on a global position, is bona fide.

Compared to existing methods, embodiments of the disclosure provide better indoor and in city building coverage, because the navigation message **134** is superposed on both the civil C/A codes and secret Y codes broadcast by the navigation satellites **102**. As explained above, a significant fraction of the power in the secret Y code signals component may be lost when the navigation satellite signal **116** passes through the band pass filter **204**. For GPS, the signals modulated by the secret Y code signals have a noise equivalent bandwidth of 10 MHz, whereas the noise equivalent bandwidth of the civil C/A code signals is 1 MHz. The civil C/A code signals are utilized by the navigation satellite receiver **200** in the client **108** such as a cell phone, not generally the secret Y code signals. Hence, the band pass filter **204** (e.g., of the cell phone) has bandwidths of only a few MHz, and so an appreciable fraction of signal power of the secret Y code signals is lost.

Compared to existing methods, embodiments of the disclosure significantly improve indoor and downtown coverage of satellite-based authentication based on the navigation satellite receiver **200** comprised in the client **108** such as a cell phone and other relatively inexpensive platforms. Embodiments achieve this gain by using a random (pseudo-random) nature of the navigation data bits **136** in the navigation message(s) **134**, and not the random (pseudo-random) nature of the secret Y code signals. The navigation message **134** modulates the civil C/A code and secret Y codes, and so the above-mentioned band pass filtering loss is not incurred. This power savings may be approximately 6 dB.

In addition, a message capacity (e.g., number of data bits) occupied by a location signature (e.g., **138** in FIG. 1, and **606** in FIG. 6) based on the civil C/A code is approximately ten times smaller than the message capacity occupied by a location signature that must include the bandwidth of the secret Y code signals (Y code). For example, if a location signature including a bandwidth of the secret Y code signals occupies about 24 kBytes, then the client location signature set **138/606** according to the embodiments of the disclosure may occupy about 2.4 KBytes. Alternatively, embodiments may populate a 24 KByte message, and may use an increased length of data bits to improve performance in low signal-to-noise-ratio (SNR) environments.

The navigation messages **134** that modulate the spectrum-spreading code **132** vary at 50 to 1000 bits per second. Moreover, much of the navigation message **134** can be predicted in advance. A low rate and predictability suggests that a data stream of the navigation message **134** may be a poor source of authentication signatures. However, certain portions of the navigation message **134** may be difficult to predict. Moreover, embodiments derive an authentication signature based on an overlap of the navigation message **134** for several, preferably many, satellites such as the navigation satellites **102**, **104**, and **106**.

FIG. 5 is an illustration of an exemplary diagram **500** showing an overlap of navigation messages **502**, **504**, and **506** from the navigation satellites **102**, **104**, and **106** respectively. As shown in FIG. 5, such an overlap does have a complex structure, because navigation bit boundaries **508**, **510**, and **512** of each of the navigation bits **520**, **522** and **524** in the navigation messages **502**, **504**, and **506** are shifted in time **514** from satellite to satellite. The shift in the time **514** from satellite to satellite can occur because, for example, a range from each of the navigation satellites **102-106** to the client **108** can differ appreciably. A satellite-to-satellite time shift such as the time shift **516** can be estimated using various techniques. A navigation bit duration **518** of the navigation bits **520**, **522** and **524** in the navigation messages **502**, **504**, and **506** may comprise, for example, 20 ms  $\approx 6000$  km/speed-of-light.

FIG. 6 is an illustration of an exemplary diagram **600** showing the navigation messages **502-506** from the navigation satellites **102-106** shown in FIG. 5 are sampled over slightly greater than one navigation bit duration **518** (e.g., 20 ms FIG. 5) according to an embodiment of the disclosure. A sampling window **602** of, for example, 25 ms is slightly longer than the navigation bit duration **518** (e.g., 20 ms) for one navigation bit of each of the navigation messages **502-506**. A duration of the sampling window **602** longer than the navigation bit duration **518** can guarantee that the sampling window **602** straddles a navigation bit boundary such as the navigation bit boundaries **508**, **510** and **512** shown in FIG. 5. For example, four possible sequences may exist for each of the navigation satellites **102**, **104** and **106**

representing two navigation bits within the sampling window **602** for each of the navigation satellites **102-106**. These are distinguished by two bit polarities “++”, “+-”, “-+” and “--”. If there are K satellites in view, then a cardinality of a location signature **606** comprising all satellite combinations for one straddled navigation bit boundary is  $2^{2K}$ . If the sampling window **602** is longer to cover a larger number of navigation bit boundaries, then a cardinality of the location signature set **606** increases rapidly (e.g., for 3 navigation bit boundaries  $2^{4K}$ , for 4 navigation bit boundaries  $2^{5K}$ , etc.).

In one embodiment, the location signature set **606** comprises an exclusive OR (XOR) of sample-bit strings such as sample-bit frames **616**, **618** and **620** comprising the navigation data bits **136** (e.g., navigation bits **520**, **522** and **524**) of each of the navigation messages **502-506** from the navigation satellites **102-106** respectively. For example, sample-bit columns **608**, **610**, **612**, and **614** of the sample-bit frames **616**, **618** and **620** are XOR'd to produce the location signature set **606**. The location signature set **606** may be produced by any suitable function such as, for example but without limitation, a logical XOR function, a logical OR function, a logical AND function, or other suitable function. For the client **108**, the sample-bit frames **616**, **618** and **620** comprise the client bit frames **1030** (FIG. 10), and the location signature set **606** comprises the client signature set **138**. For the authentication server **112**, the sample-bit frames **616**, **618** and **620** comprise synchronized server bit frames **1032** (FIG. 10), and the location signature set **606** comprises the server signature set **140**.

Thereby, a size of the location signature set **606** is reduced from a size of a combination of the sample-bit frames **616**, **618** and **620**. If the sampling window **602** is chosen to straddle only one navigation bit boundary, then the location signature set **606** resulting from an XOR has a cardinality of  $2^{K+1}$ . As shown in the Table **604** ( $N=K+1$ ), the cardinality  $2^{K+1}$  for XOR grows much more slowly than the cardinality  $2^{2K}$  (i.e.,  $2^{2K}=4^K$ ) for all satellite combinations for one navigation bit boundary. Thus, the cardinality for an XOR of satellite navigation bit boundaries grows much more slowly than the cardinality for all combinations of satellite navigation bit boundaries.

FIG. 7 is an illustration of an exemplary diagram **700** showing the navigation messages **502-506** from the navigation satellites **102-106** shown in FIG. 5 are sampled over several bit durations according to an embodiment of the disclosure. In the embodiment shown in FIG. 7, a location signature set **706** comprises an exclusive OR (XOR) (e.g., along a sample-bit column **708**) of sample-bit strings such as sample-bit frames **710**, **712** and **714** comprising navigation data bits **136** (e.g., navigation bits **520**, **522** and **524**) of each of the navigation messages **502-506** from the navigation satellites **102-106**.

For example, sample-bit columns (e.g., the sample-bit column **708**) of the sample-bit frames **710**, **712** and **714** are XOR'd to produce the location signature set **706**. The location signature set **706** may be produced by any suitable function such as, for example but without limitation, a logical XOR function, a logical OR function, a logical AND function, or other suitable function. For the client **108**, the sample-bit frames **710**, **712** and **714** comprise the client bit frames **1030** (FIG. 10), and the location signature set **706** comprises the client signature set **138**. For the authentication server **112**, the sample-bit frames **710**, **712** and **714** comprise synchronized server bit frames **1032** (FIG. 10), and the location signature set **706** comprises the server signature set **140**.

A sampling window **702** of 65 ms is slightly longer than 60 ms (three navigation bits at 20 ms each). In this case, the sampling window **702** straddles at least three bit boundaries, and the cardinality of the signature set is  $2^{4K}$ . In general, the signature set **138** contains  $2^{K \lceil T/TB \rceil}$  possible signatures, where T is a duration of the sampling window **602/702**, and TB is the navigation bit duration **518** (FIG. 5) of a navigation bit **520**. This result is plotted in FIG. 8. As shown in FIG. 8, the signature set **802** grows large very quickly as T grows beyond TB.

FIG. 8 is an illustration of an exemplary diagram **800** showing a number of location signature **802/804** (location signature set **802/804**, similar to the client signature set **138**) provided according to two embodiments of the disclosure for K=10 satellites in view. FIG. 8 shows a number of location signatures vs. sampling window **602/702**. The signature set **802** is plotted based on the following relationship:  $\text{DataCombos}[T, TB, K] = 2^{K \lceil T/TB \rceil}$ . As shown in FIG. 8, the signature set **802** grows large very quickly as T grows beyond TB. Where DataCombos represent the location signature set **802** as a function of T, TB and K.

The signature set **804** are plotted for the XOR cardinality based on the following relationship:  $\text{XORCombos}[T, TB, K] = 2^{K \lfloor T/TB \rfloor}$ . Where XORCombos represents the signature set **804** as a function of T, TB and K. Thus, XOR combination of the signature data achieves simplicity at a possible price of security. Using the XOR combination is application dependent. Each application can dictate whether this trade is appropriate based on for example a desired security level.

FIG. 9 is an illustration of an exemplary functional block diagram of an authentication system **900** (system **900**) according to an embodiment of the disclosure. Some embodiments of the system **900** may comprise additional components and elements configured to support known or conventional operating features that need not be described in detail herein. In the embodiment shown in FIG. 9, the system **900** can be used to transmit and receive data in the wireless communication environment **100**. System **900** may have functions, material, and structures that are similar to the embodiments shown in FIGS. 1-8. Therefore common features, functions, and elements may not be redundantly described here.

The system **900** generally comprises the client **108** and the authentication server **112**.

The client **108** may comprise a client demodulation module **942** comprising the down converter **202** and the ADC **206**. The client **108** may further comprise a sample data module **902**, an encryption module **904**, a client processor module **906** (processor module **906**), and a client memory module **908** (memory module **908**). The client signature set **138** sent from the client **108** to the authentication server **112** comprises the RF/IF signature **208**. The RF/IF signature **208** comprises samples of the client received navigation signals **146** (radio frequency (RF) or intermediate frequency (IF) signal) captured by the client antenna **110** at the client **108**. The sample data module **902** samples the digital client received navigation signals **222** at the bandwidth of the C/A code ( $BW_{CA}$ ) to provide the client signature set **138**.

In the embodiment shown in FIG. 9, the client **108** need not track the client received navigation signals **146** nor demodulate the navigation data bits **136** of the navigation message **134**. As shown in FIG. 9, tracking and bit demodulation are performed by a tracking and bit demodulation module **928** located at the authentication server **112**.

## 11

The authentication server 112 may comprise the server antenna 114, a server demodulation module 940, an authentication decision module 924, a tracking and bit demodulation module 922 (1106 in FIG. 11), a decryption module 930, a server processor module 932 (processor module 932) and a server memory module 934 (memory module 934).

The server demodulation module 940 comprises, a down converter 912 configured to perform conversion from RF to baseband, a band pass filter 914 configured to perform a band pass filtering, an ADC 916 configured to perform analog to digital conversion, a code wipeoff 918 configured to remove the spectrum-spreading code 132 (C/A code), and a carrier wipeoff 920 configured to remove the in-phase carrier 130.

The tracking and bit demodulation module 922 is configured to estimate the navigation data bits 136 of the navigation message 134 from the server received navigation signals 148 to provide the server signature set 140.

The tracking and bit demodulation module 928 is configured to estimate the navigation data bits 136 of the navigation message 134 contained in the RF/IF signature 208 from the client 108 to provide the client signature set 138.

The authentication decision module 924 compares the client signature set 138 and the server signature set 140 to generate the authentication decision message 144 based on the comparison. This comparison can be made on a satellite-by-satellite data comparison basis or based on any number of intermediate functions such as, for example but without limitation, a logical XOR function, a logical OR function, a logical AND function, or other function suitable for operation of the system 900 as explained in more detail in the context of discussion of FIG. 10 below.

Encryption module 904 and decryption module 930 are used to further strengthen authentication performance. A client-unique key (or device signature) is concatenated with a GNSS signature set from the client (client signature set 138). The client-unique key may be based on, for example but without limitation, cryptographic symmetric cryptography (e.g., AES), asymmetric cryptography (e.g. public-private cryptography), physically unclonable functions (PUFs), or other cryptography. The client-unique key is used to modify the client signature set 138 so that position verification at the authentication server 112 requires a copy of the client-unique key. The decryption module 930 may be used to decrypt communication from the encryption module 904. Alternatively, the client-unique key may be used to modify the server signature set 140 in the same manner as the client signature set 138. Thereby, comparison and authentication of the client signature set 138 with the server signature set 140 is generally only successful if the client 108 and the authentication server 112 use a same client-unique key.

A navigation satellite signature can be considered as a plaintext for a device encryption. The navigation satellite signature may also contain an underlying client position velocity time feedforward (PVTF) information that will also be verified by correlating the navigation satellite signature captured by the client 108 with corresponding data at a navigation satellite reference receiver. Thus, a concatenated security system is generated.

Processor modules 906/932 may be implemented, or realized, with a general purpose processor, a content addressable memory, a digital signal processor, an application specific integrated circuit, a field programmable gate array, any suitable programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof, designed to perform the functions

## 12

described herein. In this manner, a processor may be realized as a microprocessor, a controller, a microcontroller, a state machine, or the like.

A processor may also be implemented as a combination of computing devices, e.g., a combination of a digital signal processor and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a digital signal processor core, or any other such configuration. In practice, processor modules 906/934 comprise processing logic that is configured to carry out the functions, techniques, and processing tasks associated with the operation of the system 900.

In particular, the processing logic is configured to support the authentication method described herein. For, example the client processor module 906 may be suitably configured to send the client signature set 138 from the client 108 to the authentication server 112 via a client transmit antenna (not shown). For another example, the server processor module 932 may be suitably configured to send the authentication decision message 144 to another server or to the client 108 via a server transmit antenna (not shown). Furthermore, the steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in firmware, in a software module executed by processor modules 906/932, or in a combination thereof.

The memory modules 908/934, may be realized as a non-volatile storage device (non-volatile semiconductor memory, hard disk device, optical disk device, and the like), a random access storage device (for example, SRAM, DRAM), or any other form of storage medium known in the art. The memory module 908/934 may be coupled to the processor modules 906/932 respectively such that the processor modules 906/932 can read information from, and write information to, memory modules 908/934.

As an example, the processor module 906 and memory module 908, the processor module 932 and the memory module 934 may reside in their respective ASICs. The memory modules 908 and 934 may also be integrated into the processor modules 906 and 932 respectively. In an embodiment, the memory module 908/934 may include a cache memory for storing temporary variables or other intermediate information during execution of instructions to be executed by processor modules 906/932. The memory modules 908/934 may also include non-volatile memory for storing instructions to be executed by the processor modules 906/932.

For example, the memory modules 908/934 may include a location database (not shown) for storing the location signature set 802/804, and other data in accordance with an embodiment of the disclosure. For another example, the client memory module 908 may store the replica of the digital client received navigation signals 222 at the client 108. Those skilled in the art will understand that the various illustrative blocks, modules, circuits, and processing logic described in connection with the embodiments disclosed herein may be implemented in hardware, computer-readable software, firmware, or a combination thereof. To clearly illustrate this interchangeability and compatibility of hardware, firmware, and software, various illustrative components, blocks, modules, circuits, and steps are described generally in terms of their functionality.

In some embodiments, system 900 may comprise any number of processor modules, any number of memory modules, any number of transmitter modules, and any number of receiver modules suitable for their operation described herein. The illustrated system 900 depicts a simple embodiment for ease of description. These and other ele-

## 13

ments of the system **900** are interconnected together, allowing communication between the various elements of system **900**. In one embodiment, these and other elements of the system **900** may be interconnected together via a data communication bus (not shown).

A transmitter module (not shown) and a receiver module (not shown) may be located in each processor module **906/932** coupled to their respective shared antenna (not shown). Although in a simple module only one shared antenna may be used, more sophisticated modules may be provided with multiple and/or more complex antenna configurations. Additionally, although not shown in this FIG. 9, those skilled in the art will recognize that a transmitter may transmit to more than one receiver, and that multiple transmitters may transmit to the same receiver.

Whether such functionality is implemented as hardware, firmware, or software depends upon the particular application and design constraints imposed on the overall system. Those familiar with the concepts described herein may implement such functionality in a suitable manner for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

FIG. 10 is an illustration of an exemplary block diagram showing an authentication system **1000** (system **1000**) according to an embodiment of the disclosure. The system **1000** may comprise a client data frame selector module **1006**, a client data operation module **1002**, a server data frame selector module **1010**, and a server data operation module **1004**.

The client data frame selector module **1006** and the client data operation module **1002** may be implemented in the client **108** or in the server **112** so as to receive a plurality of demodulated client received navigation signals **1020** such as the navigation messages **502/504/506** as an input and generate the client signature set **138** as an output. In various embodiments, the client data frame selector module **1006** and/or the client data operation module **1002** may be located in, for example, the authentication decision module **924**, the tracking and bit demodulation module **928**, a bit selector module **1104** (FIG. 11), a tracking and bit demodulation module **1102** (FIG. 12), or other suitable location.

In various embodiments, server data frame selector module **1010** and/or the server data operation module **1004** may be located in, for example, the authentication decision module **924**, the tracking and bit demodulation module **922**, or other suitable location.

For example but without limitation, the demodulated client received navigation signals **1020** may be produced by the tracking and bit demodulation module **928**. The server data frame selector module **1010** and the server data operation module **1004** may be implemented in the authentication decision module **924** of the system **900** so as to receive a plurality of demodulated server received navigation signals **1022** such as the navigation messages **502/504/506** as an input and generate the server signature set **140** as an output. For example but without limitation, the demodulated server received navigation signals **1022** may be produced and synchronized to the demodulated client received navigation signals **1020** by the tracking and bit demodulation module **922**.

The client data frame selector module **1006** is configured to select a subset of the demodulated client received navigation signals **1020** to provide a plurality of client bit frames **1030**. The subset may comprise, for example but without limitation, a subframe, a random selection, and a selection of bits from most dynamic bits, or other subset.

## 14

The client data operation module **1002** is configured to compute a function such as an XOR **1008** of the client bit frames **1030** to provide a client signature set **138**. The function may comprise, for example but without limitation, a logical XOR function, a logical OR function, a logical AND function, or other suitable function.

The server data frame selector module **1010** is configured to select a subset of the demodulated server received navigation signals **1022** synchronized to the client bit frames **1030** to provide a plurality of synchronized server bit frames **1032**.

The server data operation module **1004** is configured to compute the function such as an XOR **1012** of the synchronized server bit frames **1032** to provide a server signature set **140**.

The server correlation module **142** is configured to compare the client signature set **138** and the server signature set **140** to provide a comparison result such as the authentication decision message **144**. The authentication decision module **924** is configured to generate the authentication decision message **144** to authenticate the location **122** of the client **108** based on the comparison result. This comparison can be made on a satellite-by-satellite data comparison basis or based on any number of intermediate functions such as, for example but without limitation, a logical XOR function, a logical OR function, a logical AND function, or other suitable function.

FIG. 11 is an illustration of an exemplary functional block diagram of an authentication system **1100** (system **1100**) according to an embodiment of the disclosure. System **1100** may have functions, material, and structures that are similar to the embodiments shown in FIGS. 1-9. Therefore common features, functions, and elements may not be redundantly described here.

System **1100** may comprise the client **108** and the authentication server **112** (server device). The client **108** may comprise, a client demodulation module **1108** comprising, the down converter **202** configured to perform conversion from RF to baseband, the band pass filter **204** configured to perform a band pass filtering, the ADC **206** configured to perform analog to digital conversion, the code wipeoff **210** configured to remove the spectrum-spreading code **132** (C/A code), and the carrier wipeoff **212** configured to remove the in-phase carrier **130**. The client **108** may also comprise the tracking and bit demodulation module **1102**, and the bit selector module **1104**.

The bit selector module **1104** is configured to choose navigation data bits **136** from portions of the navigation messages **134** that are known to vary unpredictably. The bit selector module **1104** identifies frames, subframes and words in the navigation message **134**, and selects a multiplicity of words that are known to contain variable data. The bit selector module **1104** avoids fields that change infrequently and thus are readily predicted. For example, data fields that describe the navigation satellites **102-106** ephemeris would be avoided by the bit selector module **1104**.

An advantage of the system **1100** is that the client **108** can use the bit selector module **1104** to choose navigation data bits **136** from portions of the navigation messages **134** that are known to vary unpredictably. Some part of the navigation messages **134** may be very predictable and so may be prone to spoofing. Using samples of the navigation messages **134** that are dynamic where the navigation data bits **136** change often randomizes the client signature set **138**.

System **1100** makes use of the tracking and bit demodulation module **1102** that is generally present in many GPS receivers which may be present in various GPS receivers for

15

cell phones. The client **108** tracks the client received navigation signals **146** and demodulates the navigation data bits **136** of the navigation message **134** using the tracking and bit demodulation module **1102** to estimate the navigation data bits **136**. The estimated navigation data bits **1110** are then used by the bit selector module **1104** to choose navigation data bits from portions of the navigation messages **134** that are known to vary unpredictably to provide the client signature set **138**. The client signature set **138** is then sent to the authentication server **112** for comparison with the server signature set **140**.

FIG. **12** is an illustration of an exemplary functional block diagram of an authentication system **1200** (system **1200**) according to an embodiment of the disclosure. System **1200** may have functions, material, and structures that are similar to the embodiments shown in FIGS. **1-11**. Therefore common features, functions, and elements may not be redundantly described here.

FIG. **12** shows an embodiment where the authentication server **112** provides a test waveform **1208** to the client **108**. In other words, the authentication server **112** pushes a candidate signature out to the client **108**. The test waveform **1208** may be a binary sequence or may be an XOR operation of the navigation data bit **136** for the satellites known to be in view of the client **108**. The client **108** correlates or compares the test waveform **1208** at the client correlator **1204** with the navigation bits **1206** demodulated at the client **108** by the tracking and demodulator module **1102**, and sends the correlation information **1210** of this correlation (or comparison) back to the authentication server **112**. The authentication server **112** makes the final authentication decision based on the correlation information **1210** from the client **108**.

In the embodiments shown in FIGS. **9-12** and described above, the authentication action may be initiated by any of the following events:

The client **108** wishes to complete a transaction or request.

The client **108** is prompted to seek authentication based on its interaction with a point-of-sale terminal or near field communication (NFC).

The client **108** is in a pre-established safe zone such as home or work, and wishes to pre-establish authentication for anticipated transactions or requests.

The client **108** is in a pre-established safe zone, and wishes to post-authenticate a transaction or request that has taken place in the recent past.

The client **108** senses that the GNSS signals are becoming weaker, and thus want to pre-establish authentication for potential indoor transactions or requests.

The authentication server **112** (server device) requests an authentication action.

FIG. **13** is an illustration of an exemplary authentication process according to an embodiment of the disclosure. The various tasks performed in connection with the process **1300** may be performed by software, hardware, firmware, a computer-readable medium having computer executable instructions for performing the process method, or any combination thereof. The process **1300** may be recorded in a computer-readable medium such as a semiconductor memory, a magnetic disk, an optical disk, and the like, and can be accessed and executed, for example, by a computer CPU such as the processor modules **906/932** in which the computer-readable medium is stored.

It should be appreciated that process **1300** may include any number of additional or alternative tasks, the tasks shown in FIG. **13** need not be performed in the illustrated

16

order, and process **1300** may be incorporated into a more comprehensive procedure or process having additional functionality not described in detail herein. In some embodiments, portions of the process **1300** may be performed by different elements of the systems **900-1200** such as: the client **108**, the authentication server **112**, etc. Process **1300** may have functions, material, and structures that are similar to the embodiments shown in FIGS. **1-12**. Therefore common features, functions, and elements may not be redundantly described here.

Process **1300** may begin by receiving client received satellite navigation signals such as the client received satellite navigation signals **146** at a client device such as the client device **108** (task **1302**).

Process **1300** may then continue by demodulating the demodulated client received navigation signals such as the navigation messages **502/504/506** from the client received satellite navigation signals **146** received at the client device **108** from a plurality of navigation satellites such as the navigation satellites **102-106** respectively (task **1304**). In some embodiments, demodulating the demodulated client received navigation signals from the client received satellite navigation signals **146** may comprise conversion from RF to baseband, and analog to digital conversion. In some embodiments, demodulating the demodulated client received navigation signals from the client received satellite navigation signals **146** further comprises code wipe-off and carrier wipe-off. The navigation satellites may comprise, for example but without limitation, a Global Navigation Satellite System (GNSS) satellite, a Global Positioning System (GPS™) satellite, a Globalnaya Navigatsionnaya Sputnikovaya Sistema (GLONASS™) satellite, a BeiDou Navigation System (COMPASS™) satellite, a Galileo™ satellite, or other satellite navigation system. The demodulated client received navigation signals **502/504/506** and the navigation messages **502/504/506** may be used interchangeably in this document.

Process **1300** may then continue by selecting a subset of the plurality of demodulated client received navigation signals to provide a plurality of client bit frames such as the client bit frames **1030** (task **1306**). The subset may comprise, for example but without limitation, a subframe, a random selection, a selection of bits from most dynamic bits, or other subset.

Process **1300** may then continue by receiving a server received satellite navigation signals such as the server received satellite navigation signals **148** at a server antenna such as the server antenna **114** (task **1308**).

Process **1300** may then continue by demodulating the demodulated server received navigation signals such as the navigation messages **502/504/506** from the server received satellite navigation signals **148** received at the server antenna **114** from the navigation satellites **102-104** respectively (task **1310**). In some embodiments, demodulating the demodulated server received navigation signals such as the navigation messages **502/504/506** from the server received navigation satellite signals **148** comprises conversion from RF to baseband, band pass filtering, analog to digital conversion, code wipe-off, and carrier wipe-off. The demodulated server received navigation signals **502/504/506** and the navigation messages **502/504/506** may also be used interchangeably in this document.

Process **1300** may then continue by selecting a subset of the demodulated server received navigation signals such as the navigation messages **502/504/506** synchronized to the

17

client bit frames **1030** to provide a plurality of synchronized server bit frames such as the synchronized server bit frames **1032** (task **1312**).

Process **1300** may then continue by computing a function of the client bit frames **1030** to provide a client signature set such as the client signature set **138** (task **1314**). The function may comprise, for example but without limitation, a logical XOR function, a logical OR function, a logical AND function, or other function.

Process **1300** may then continue by computing the function of the synchronized server bit frames **1032** to provide a server signature set such as the server signature set **140** (task **1316**).

Process **1300** may then continue by comparing the client signature set **138** and the server signature set **140** to provide a comparison result such as the authentication decision message **144** (task **1318**).

Process **1300** may then continue by authenticating a location such as the location **122** of the client device **108** based on the comparison result (task **1320**). Authenticating indicates a validity that there is acceptable accuracy and/or certainty that the client **108** is located at the location **122**, or indicates invalidity that there is not acceptable accuracy and/or certainty that the client **108** is located at the location **122**. Also, the process **1300** may continue by transmitting the client signature set **138** to the authentication server **112** for authentication of the location **122** of the client device **108** (task **1322**).

FIG. **14** is an illustration of an exemplary authentication process according to an embodiment of the disclosure. The various tasks performed in connection with the process **1400** may be performed by software, hardware, firmware, a computer-readable medium having computer executable instructions for performing the process method, or any combination thereof. The process **1400** may be recorded in a computer-readable medium such as a semiconductor memory, a magnetic disk, an optical disk, and the like, and can be accessed and executed, for example, by a computer CPU such as the processor modules **906/932** in which the computer-readable medium is stored.

It should be appreciated that process **1400** may include any number of additional or alternative tasks, the tasks shown in FIG. **14** need not be performed in the illustrated order, and process **1300** may be incorporated into a more comprehensive procedure or process having additional functionality not described in detail herein. In some embodiments, portions of the process **1300** may be performed by different elements of the systems **900-1200** such as: the client **108**, the authentication server **112**, etc. Process **1400** may have functions, material, and structures that are similar to the embodiments shown in FIGS. **1-12**. Therefore common features, functions, and elements may not be redundantly described here.

Process **1400** may begin by receiving a client received satellite navigation signals such as the client received navigation signals **146** at a client device such as the client device **108** (task **1402**).

Process **1400** may then continue by demodulating the demodulated client received navigation signals such as the navigation messages **502/504/506** from the client received satellite navigation signals received at the client device **108** from a plurality of navigation satellites such as the navigation satellites **102-108** respectively (task **1404**).

Process **1400** may then continue by sending a test waveform such as the test waveform **1208** from a server device such as the server device **112** to the client device **108** (task **1406**).

18

Process **1400** may then continue by comparing the test waveform **1208** at the client device **108** with the demodulated client received navigation signals at the client device **108** to provide correlation information such as the correlation information **1210** (task **1408**).

Process **1400** may then continue by sending the correlation information **1210** back to the server device **112** to provide an authentication decision message such as the authentication decision message **144** (task **1410**).

In this manner, embodiments of the disclosure provide an authentication system that allows adequate sensitivity for a navigation satellite signal to be received at a client device located in a low signal-to-noise-ratio (SNR) environment such as indoors and downtown.

While at least one example embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the example embodiment or embodiments described herein are not intended to limit the scope, applicability, or configuration of the subject matter in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing the described embodiment or embodiments. It should be understood that various changes can be made in the function and arrangement of elements without departing from the scope defined by the claims, which includes known equivalents and foreseeable equivalents at the time of filing this patent application.

In this document, the term “module” as used herein, refers to software, firmware, hardware, and any combination of these elements for performing the associated functions described herein. Additionally, for purpose of discussion, the various modules are described as discrete modules; however, as would be apparent one of skilled in the art, two or more modules may be combined to form a single module that performs the associated functions according to the embodiments of the present disclosure.

In this document, the terms “computer program product”, “computer-readable medium”, and the like may be used generally to refer to media such as, for example, memory, storage devices, or storage unit. These and other forms of computer-readable media may be involved in storing one or more instructions for use by the processor modules **906/932** to cause the processor modules **906/932** to perform specified operations. Such instructions, generally referred to as “computer program code” or “program code” (which may be grouped in the form of computer programs or other groupings), when executed, enable a method of using a system such as the system **900-1200**.

The above description refers to elements or nodes or features being “connected” or “coupled” together. As used herein, unless expressly stated otherwise, “connected” means that one element/node/feature is directly joined to (or directly communicates with) another element/node/feature, and not necessarily mechanically. Likewise, unless expressly stated otherwise, “coupled” means that one element/node/feature is directly or indirectly joined to (or directly or indirectly communicates with) another element/node/feature, and not necessarily mechanically. Thus, although FIGS. **1-12** depict example arrangements of elements, additional intervening elements, devices, features, or components may be present in an embodiment of the disclosure.

Terms and phrases used in this document, and variations thereof, unless otherwise expressly stated, should be construed as open ended as opposed to limiting. As examples of the foregoing: the term “including” should be read as mean

19

“including, without limitation” or the like; the term “example” is used to provide exemplary instances of the item in discussion, not an exhaustive or limiting list thereof; and adjectives such as “conventional,” “traditional,” “normal,” “standard,” “known” and terms of similar meaning should not be construed as limiting the item described to a given time period or to an item available as of a given time, but instead should be read to encompass conventional, traditional, normal, or standard technologies that may be available or known now or at any time in the future.

Likewise, a group of items linked with the conjunction “and” should not be read as requiring that each and every one of those items be present in the grouping, but rather should be read as “and/or” unless expressly stated otherwise. Similarly, a group of items linked with the conjunction “or” should not be read as requiring mutual exclusivity among that group, but rather should also be read as “and/or” unless expressly stated otherwise.

Furthermore, although items, elements or components of the disclosure may be described or claimed in the singular, the plural is contemplated to be within the scope thereof unless limitation to the singular is explicitly stated. The presence of broadening words and phrases such as “one or more,” “at least,” “but not limited to” or other like phrases in some instances shall not be read to mean that the narrower case is intended or required in instances where such broadening phrases may be absent. The term “about” when referring to a numerical value or range is intended to encompass values resulting from experimental error that can occur when taking measurements.

As used herein, unless expressly stated otherwise, “operable” means able to be used, fit or ready for use or service, usable for a specific purpose, and capable of performing a recited or desired function described herein. In relation to systems and devices, the term “operable” means the system and/or the device is fully functional and calibrated, comprises elements for, and meets applicable operability requirements to perform a recited function when activated. In relation to systems and circuits, the term “operable” means the system and/or the circuit is fully functional and calibrated, comprises logic for, and meets applicable operability requirements to perform a recited function when activated.

The invention claimed is:

1. A method for location authentication, the method comprising:

selecting a first subset of a plurality of demodulated server received navigation signals synchronized to a plurality of client bit frames to provide a plurality of synchronized server bit frames, the first subset comprising a random selection or a selection of most dynamically changing bits of the demodulated server received navigation signals;

computing a function of the synchronized server bit frames to provide a server signature set;

comparing a client signature set and the server signature set to provide a comparison result;

authenticating a location of a client device based on the comparison result;

selecting a second subset of a plurality of demodulated client received navigation signals to provide the client bit frames, the second subset comprising the random selection or the selection of most dynamically changing bits corresponding to the first subset; and

computing the function of the client bit frames to provide the client signature set.

20

2. The method of claim 1, wherein the function comprises one of: a logical XOR function, a logical OR function, and a logical AND function.

3. The method of claim 1, further comprising demodulating the demodulated client received navigation signals from a plurality of client received satellite navigation signals received at the client device from a plurality of navigation satellites respectively.

4. The method of claim 3, wherein demodulating the demodulated client received navigation signals from the client received satellite navigation signals comprises:

conversion from RF to baseband;

band pass filtering; and

analog to digital conversion.

5. The method of claim 4, wherein demodulating the demodulated client received navigation signals from the client received satellite navigation signals further comprises:

code wipe-off; and

carrier wipe-off.

6. The method of claim 4, wherein the authenticating further comprises:

sending a test waveform from a server device to the client device;

comparing the test waveform at the client device with the demodulated client received navigation signals at the client device to provide correlation information; and sending the correlation information back to the server device to provide an authentication decision message.

7. The method of claim 3, further comprising receiving the client received satellite navigation signals at the client device.

8. The method of claim 3, further comprising demodulating the demodulated server received navigation signals from a plurality of server received satellite navigation signals received at a server antenna from the navigation satellites respectively.

9. The method of claim 8, further comprising receiving the server received satellite navigation signals at the server antenna.

10. The method of claim 8, wherein demodulating the demodulated server received navigation signals from the satellite navigation signals comprises:

conversion from RF to baseband;

band pass filtering;

analog to digital conversion;

code wipe-off; and

carrier wipe-off.

11. A location authentication system comprising:

a server data frame selector module operable to select a first subset of a plurality of demodulated server received navigation signals synchronized to a plurality of client bit frames to provide a plurality of synchronized server bit frames, the first subset comprising a random selection or a selection of most dynamically changing bits of the demodulated server received navigation signals;

a server data operation module operable to compute a function of the synchronized server bit frames to provide a server signature set;

a server correlation module operable to compare a client signature set and the server signature set to provide a comparison result;

an authenticate module operable to authenticate a location of a client device based on the comparison result;

a client data frame selector module operable to select a second subset of a plurality of demodulated client received navigation signals to provide the client bit



**21**

frames, the second subset comprising the random selection or the selection of most dynamically changing bits corresponding to the first subset; and  
 a client data operation module operable to compute the function of the client bit frames to provide the client signature set.

**12.** The system of claim **11**, further comprising a client demodulation module operable to:

receive a plurality of client received satellite navigation signals at the client device from a plurality of navigation satellites respectively; and

demodulate the demodulated client received navigation signals from the client received satellite navigation signals.

**13.** The system of claim **12**, wherein the client demodulation module is further operable to:

perform conversion from RF to baseband;  
 band pass filtering; and  
 perform analog to digital conversion.

**22**

**14.** The system of claim **12**, wherein the client demodulation module is further operable to:  
 perform code wipe-off; and  
 perform carrier wipe-off.

**15.** The system of claim **11**, further comprising a server demodulation module operable to:

receive a plurality of server received satellite navigation signals at a server device from the navigation satellites respectively; and

demodulate the demodulated server received navigation signals from the server received satellite navigation signals.

**16.** The system of claim **15**, wherein the server demodulation module is further operable to:

perform conversion from RF to baseband;  
 band pass filtering;  
 perform analog to digital conversion;  
 perform code wipe-off; and  
 perform carrier wipe-off.

\* \* \* \* \*